Cambridge IGCSE · Chemistry 0620 · Notes

Alcohols and carboxylic acids

Read online at **pastopic.com/cambridge/chemistry-0620/notes/alcohols-and-carboxylic-acids**

Last checked 30 September 2026

Read first: **Organic formulae, functional groups and naming**, **Acids, bases and oxides**

What you need to know

By the end of this topic you should be able to:

1. **Describe the two ways ethanol is manufactured**: **fermentation** of aqueous glucose at 25–$35\ ^\circ\mathrm{C}$ with yeast and without oxygen, and the **catalytic addition of steam to ethene** at $300\ ^\circ\mathrm{C}$ and $60\ \mathrm{atm}$ ($6000\ \mathrm{kPa}$) with an acid catalyst.
2. **Describe the combustion of ethanol**: what it forms with plenty of oxygen and with too little.
3. **State the uses of ethanol**: as a **solvent** and as a **fuel**.
4. **Describe the reactions of ethanoic acid** with **metals**, **bases** and **carbonates**, and give the **names and formulae of the salts** formed.
5. **Extended only: give the advantages and disadvantages** of each way of making ethanol.
6. **Extended only: describe how ethanoic acid is made by oxidising ethanol**, either with acidified aqueous potassium manganate(VII) or by bacteria when vinegar is made.
7. **Extended only: describe the reaction of a carboxylic acid with an alcohol**, using an acid catalyst, **to form an ester**.

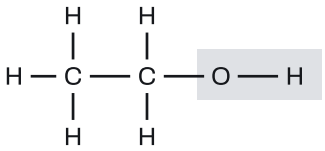
Questions on this topic also ask you to draw ethanol and ethanoic acid, to use the general formulae of the two series, and (Extended) to name and draw the alcohols, carboxylic acids and esters with up to four carbon atoms in each part (syllabus 11.1–11.2). The Organic formulae, functional groups and naming note teaches those; this note recaps only what these questions need.

Understand it

Two families with an oxygen-containing group

Alcohols have the **–OH** functional group (the hydroxyl group) joined to a carbon atom. Their names end in **-ol**. **Carboxylic acids** have the **–COOH** functional group: a carbon atom with a C=O double bond and an –O–H on it. Their names end in **-oic acid**.

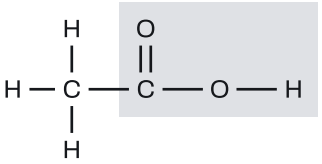
ethanol
C_2H_5OH



alcohol group, –OH

8 single bonds

ethanoic acid
CH_3COOH



carboxylic acid group, –COOH

one C=O double bond

- **Ethanol**, C_2H_5OH (also written CH_3CH_2OH): 5 C–H, 1 C–C, 1 C–O and 1 O–H bond, so **8 single bonds** and no double bond.
- **Ethanoic acid**, CH_3COOH: 3 C–H, 1 C–C, **1 C=O**, 1 C–O and 1 O–H. Its displayed formula must show the C=O as two lines.

Neither is a hydrocarbon: they contain **oxygen** as well as carbon and hydrogen. Both are **covalent** compounds, colourless liquids that mix with water. Ethanol is **not unsaturated**: it has no C=C, and the C=O in an acid does not count.

Recap from the Organic formulae note: the general formulae are $C_nH_{2n+1}OH$ for alcohols and $C_nH_{2n+1}COOH$ for carboxylic acids (methanoic acid, $HCOOH$, has $n = 0$). The name counts every carbon, including the one in –COOH. Each series is a **homologous series** with the **same functional group**, so its members have similar chemical properties, and their boiling points rise as the chain gets longer. Names, isomers such as propan-1-ol and propan-2-ol, and the other characteristics of a series are taught in that note.

Making ethanol: fermentation

Yeast turns sugar into ethanol and carbon dioxide:

$$\text{glucose} \rightarrow \text{ethanol} + \text{carbon dioxide} \qquad C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$

The conditions, and why:

- the reactant is **aqueous glucose** (sugar dissolved in water); it is the raw material, not a condition;
- **yeast**: its enzymes catalyse the reaction (so fermentation does use a catalyst);
- 25–$35\ ^\circ C$: warm enough to be reasonably fast; much hotter and the enzymes stop working;
- **absence of oxygen** (anaerobic): with air, the yeast would not make ethanol, and bacteria would turn the ethanol into ethanoic acid.

Fermentation is slow and done in **batches**. It gives a **dilute** solution of ethanol in water, with yeast and sugar left over, so the ethanol must be separated by (fractional) distillation.

Making ethanol: adding steam to ethene

Ethene (made by cracking petroleum fractions) reacts with steam:

$$\text{ethene} + \text{steam} \rightarrow \text{ethanol} \qquad \mathrm{C_2H_4 + H_2O \rightarrow C_2H_5OH}$$

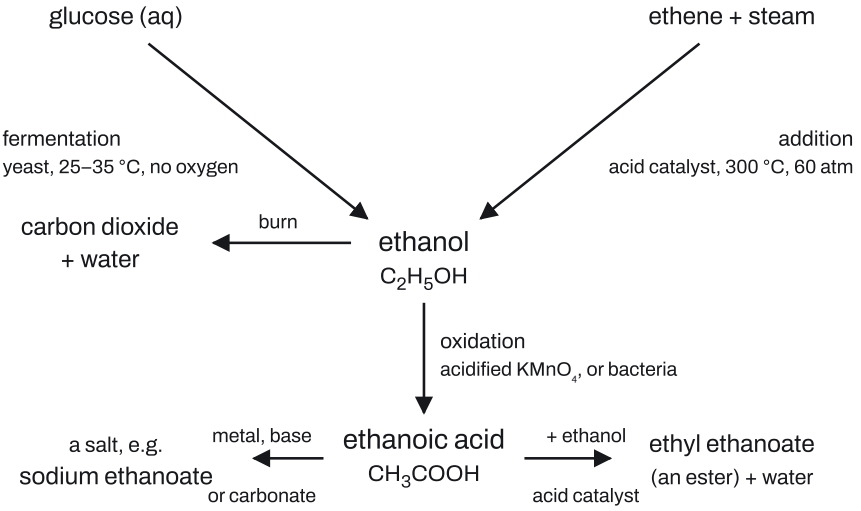
Conditions: **steam** (not liquid water), $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$ ($6000\ \mathrm{kPa}$), and an **acid catalyst** (phosphoric acid). It is an **addition** reaction (also called hydration): two molecules join to give **only one product**. The H and the OH add across the C=C, which becomes a C–C single bond, so fewer electrons are shared between the carbon atoms (4 in C=C, 2 in C–C). The product, ethanol ($M_\mathrm{r} = 46$), no longer decolourises aqueous bromine. It runs **continuously**, is **fast**, and gives almost **pure** ethanol.

Extended only: an alkene whose C=C ends differ gives two alcohols: propene gives propan-1-ol and propan-2-ol, while ethene gives only ethanol. So propan-1-ol can come from propene, $\mathrm{CH_2{=}CHCH_3}$.

Extended only: comparing the two methods

	Fermentation	Steam + ethene
raw material	glucose from crops: **renewable**	ethene from petroleum: **non-renewable**
energy	low temperature, normal pressure: **little energy**	$300\ ^\circ\mathrm{C}$ and $60\ \mathrm{atm}$: **a lot of energy**
rate	**slow**	**fast**
process	**batch**	**continuous**
product	**dilute, impure** ethanol that must be distilled	almost **pure** ethanol

So the advantages of fermentation are renewable raw materials and low energy use; its disadvantages are that it is slow, batch and gives impure ethanol. The advantages of adding steam to ethene are the reverse: fast, continuous and pure; its disadvantages are the non-renewable raw material and the high energy cost. Both methods use a catalyst (yeast, and phosphoric acid), and both release carbon dioxide somewhere (fermentation makes it; the other uses fossil fuel energy), so "no greenhouse gases" is never an advantage.



Extended only: oxidation and ester formation

Burning ethanol, and its uses

Ethanol is a **fuel** because it **releases energy (heat) when it burns**. With plenty of oxygen, complete combustion gives **carbon dioxide and water** only:

$$\mathrm{C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O}$$

To balance any alcohol: carbon atoms give the $\mathrm{CO_2}$; hydrogen atoms $\div 2$ give the $\mathrm{H_2O}$; count the O atoms needed on the right, **take away the one O already in the alcohol**, then halve to get $\mathrm{O_2}$ (double everything if you get a half). With too little oxygen (incomplete combustion) ethanol also forms **carbon monoxide** (a toxic gas) and **carbon** (soot), with water.

Uses of ethanol: a **fuel** (on its own or mixed with petrol) and a **solvent** (it dissolves many substances that water does not). When a question already gives "drinks" or "fuel", write the other one: solvent.

Ethanoic acid is a typical (but weak) acid

In water, ethanoic acid releases $\mathrm{H^+}$ **ions**, so it behaves like other acids, just more gently: it is a **weak** acid (only partly ionised), with a **pH of about 3 to 6**, not 1.

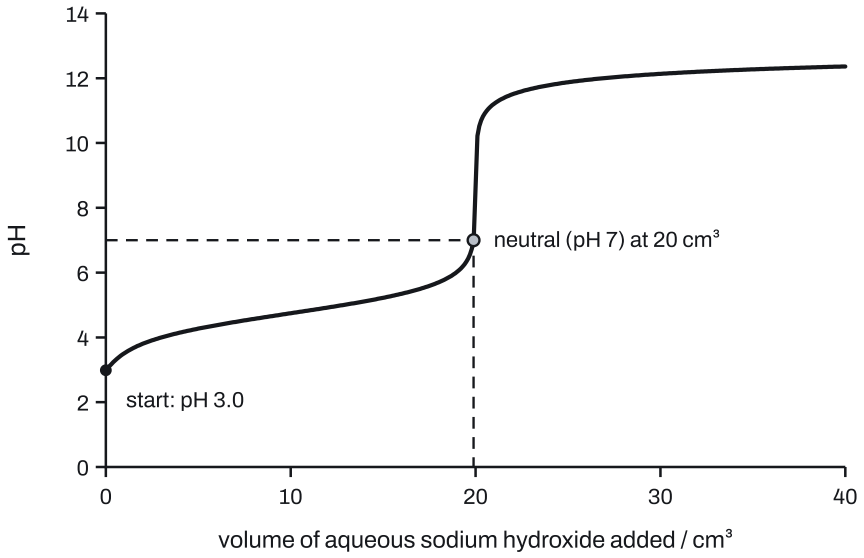
- **Indicators:** blue litmus turns **red** (red litmus stays red); universal indicator turns **yellow or orange**; methyl orange turns **red**; thymolphthalein stays **colourless**.
- **Reactive metals** (magnesium, zinc, calcium, sodium) → **salt + hydrogen**. You see fizzing (bubbles) and the metal gets smaller. Copper does not react (it is below hydrogen in the reactivity series).
- **Bases** (metal oxides and hydroxides, including alkalis) → **salt + water**. No gas. A neutralisation.
- **Carbonates** (sodium carbonate, calcium carbonate, copper(II) carbonate and so on) → **salt + carbon dioxide + water**. You see fizzing and the solid disappears. Carbonates never give hydrogen.

$$\mathrm{2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2}$$
$$\mathrm{CH_3COOH + NaOH \rightarrow CH_3COONa + H_2O}$$
$$\mathrm{2CH_3COOH + CaCO_3 \rightarrow (CH_3COO)_2Ca + CO_2 + H_2O}$$

Naming and writing the salt. The salt is named after the metal and **"ethanoate"** (sodium ethanoate, calcium ethanoate). The acid loses the H of its –COOH, leaving the **ethanoate ion** $\mathrm{CH_3COO^-}$. Balance the charges like any ionic formula: $\mathrm{Na^+}$ needs one, so $\mathrm{CH_3COONa}$; $\mathrm{Ca^{2+}}$ or $\mathrm{Mg^{2+}}$ needs two, so $\mathrm{(CH_3COO)_2Ca}$ (also written $\mathrm{Ca(CH_3COO)_2}$). Other acids work the same way: propanoic acid gives **propanoates** ($\mathrm{CH_3CH_2COO^-}$), methanoic acid **methanoates** ($\mathrm{HCOO^-}$).

An acid with two –COOH groups (such as butanedioic acid) reacts at both of them, and still gives hydrogen with a metal and carbon dioxide with a carbonate.

Reading a pH curve. When an alkali is added to ethanoic acid, the pH starts low (the acid's pH), rises slowly, then jumps. The reading at the start is the acid's pH; the volume where the curve crosses **pH 7** is the volume that made the solution neutral.



Extended only: oxidising ethanol to ethanoic acid

Oxidation changes the **–CH_2OH** end of an alcohol into **–COOH**, keeping the same number of carbon atoms. There are two ways:

- **In the laboratory:** heat ethanol with **acidified aqueous potassium manganate(VII)**. The purple manganate(VII) is reduced (it loses its colour); ethanol is the **reducing agent**, because it is oxidised.
- **Bacterial oxidation:** bacteria in the air oxidise ethanol to ethanoic acid. This is how **vinegar** (dilute ethanoic acid) is made, and why wine left open turns sour: $\mathrm{C_2H_5OH + O_2 \rightarrow CH_3COOH + H_2O}$.

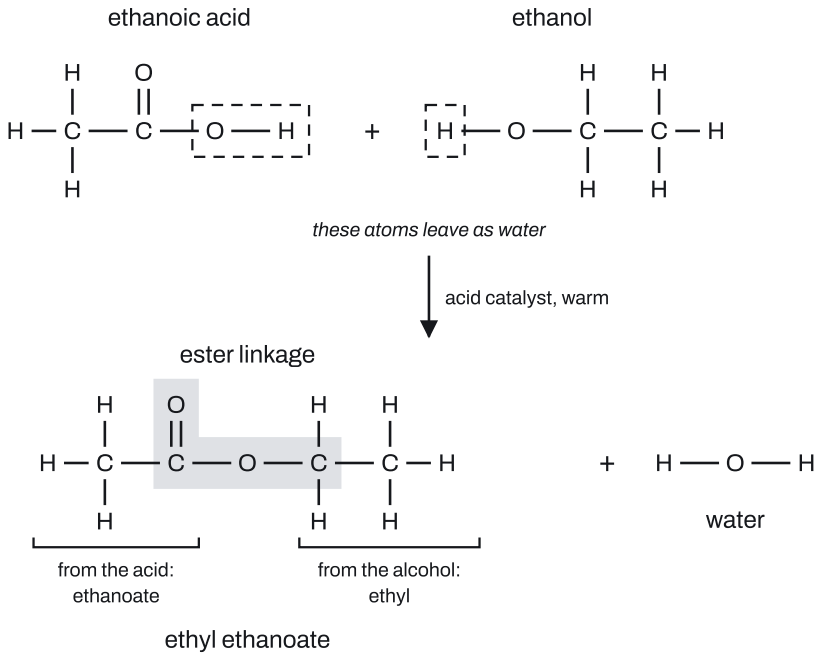
The same change works for other alcohols: propan-1-ol gives propanoic acid ($\mathrm{CH_3CH_2COOH}$), butan-1-ol gives butanoic acid, and an alcohol with an –OH at each end (a diol) gives an acid with a –COOH at each end. Ethanoic acid is **not** made by reduction, fermentation, dehydration or neutralisation.

Extended only: esters

A carboxylic acid and an alcohol, **warmed with an acid catalyst** (concentrated sulfuric acid), react to make an **ester** and **water**:

$$\text{carboxylic acid} + \text{alcohol} \rightarrow \text{ester} + \text{water} \qquad \mathrm{CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O}$$

The –OH of the acid and the H of the alcohol's –OH leave as water, and the two parts join through the **ester linkage, –COO–**.



Naming (recap from the Organic formulae note): alcohol part first as **-yl**, acid part second as **-oate**. Ethanoic acid + propan-1-ol gives **propyl ethanoate**; propanoic acid + ethanol gives ethyl propanoate, a different compound. In a formula such as $\mathrm{CH_3CH_2COOCH_3}$, the part up to and including the C of COO came from the acid (propanoate) and the part after the O from the alcohol (methyl): methyl propanoate. In a displayed formula, the chain holding the C=O carbon is the acid part.

What questions on this topic ask about the ester reaction:

- **Counting unbranched esters with n carbon atoms:** the acid part can have $1, 2, \ldots, n-1$ carbons and the alcohol part the rest, so there are $n-1$. For $\mathrm{C_5H_{10}O_2}$: methyl butanoate, ethyl propanoate, propyl ethanoate and butyl methanoate, so **4**.
- **Empirical formula:** divide by the highest common factor: $\mathrm{C_4H_8O_2} \rightarrow \mathrm{C_2H_4O}$.
- **Two –OH groups** (a diol) react with **two** acid molecules, making two ester linkages and two water molecules; so 1 mol of a diol reacts with 2 mol of a monocarboxylic acid.
- The reaction can be reversed. An ester and water give back the acid and the alcohol (hydrolysis). As acid forms, $\mathrm{H^+}$ ions appear and the pH falls from 7 to below 7; universal indicator shows the change.
- Esters burn completely to carbon dioxide and water like any compound of C, H and O; balance them the same way as alcohols.

Key facts and formulas

Nothing here is given in the exam (the paper gives only the Periodic Table), so everything below is to learn.

Formula	Status
Alcohols $\mathrm{C_nH_{2n+1}OH}$ (–OH); carboxylic acids $\mathrm{C_nH_{2n+1}COOH}$ (–COOH)	Learn it

Formula	Status
Fermentation: $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$; reactant aqueous glucose; conditions yeast, 25–$35\ ^\circ C$, no oxygen	Learn it
Hydration: $C_2H_4 + H_2O \rightarrow C_2H_5OH$; steam, acid catalyst, $300\ ^\circ C$, $60\ atm$ $(6000\ kPa)$	Learn it
Complete combustion: $C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$	Learn it
Acid + metal → salt + hydrogen; acid + base → salt + water; acid + carbonate → salt + carbon dioxide + water	Learn it
Ethanoate ion CH_3COO^-: CH_3COONa, $(CH_3COO)_2Ca$, $(CH_3COO)_2Mg$	Learn it
Extended: ethanol → ethanoic acid by acidified aqueous potassium manganate(VII), or by bacteria (vinegar)	Learn it
Extended: acid + alcohol → ester + water (acid catalyst); name = alcohol part (-yl) + acid part (-oate)	Learn it
Extended: ester $C_nH_{2n}O_2$; unbranched esters with n carbons: $n - 1$	Learn it

How to do it

In the questions we have tagged for this topic (181 questions, 2021–2025, on all four papers), the types came up this often. 53 of the 181 questions mix types, so the counts add up to more than 181.

Question type	Questions
Manufacture of ethanol: raw materials, conditions, equations	57
Recognise, name and draw alcohols and carboxylic acids	57
Reactions of carboxylic acids as acids	49
Esters: name, make, draw	41
Uses of ethanol and its combustion	23
Compare fermentation with steam + ethene	17
Oxidation of ethanol to ethanoic acid	16

1. Manufacture of ethanol: raw materials, conditions, equations (57 questions)

1. **Decide which method** the question means. Glucose, sugar or yeast: fermentation. Ethene or steam: addition (hydration). Don't mix their conditions.

2. **Fermentation, "state two (or three) conditions"**: any of **yeast**, 25–$35\ ^\circ\mathrm{C}$ (a value in this range), **absence of oxygen**. Each is a separate mark; "yeast" counts as a condition. Aqueous glucose is the **reactant**, not a condition: give it when the question asks for the reactant or raw material. Products: **ethanol and carbon dioxide**.
3. **Steam + ethene, "state the conditions"**: $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$ (or $6000\ \mathrm{kPa}$), **acid catalyst** (phosphoric acid). Give units when the question asks for them. The other reactant is **steam**.
4. **Extended: symbol equations**: $\mathrm{C_6H_{12}O_6} \rightarrow 2\mathrm{C_2H_5OH} + 2\mathrm{CO_2}$ and $\mathrm{C_2H_4} + \mathrm{H_2O} \rightarrow \mathrm{C_2H_5OH}$. The first mark is for the right reactants (glucose alone on the left; ethene and water on the left), the second for the balanced equation.

Variations you will meet:

- **Name the process**: glucose → ethanol is **fermentation**; ethene + steam → ethanol is (catalytic) **addition** or hydration, not fermentation, cracking or polymerisation.
- **Pick from a list or a table**: "manufactured by fermentation" → ethanol; "two products of fermentation" → ethanol and carbon dioxide; "a reactant in fermentation" → glucose; "used to make ethanol by fermentation" → yeast (not phosphoric acid, iron or platinum).
- **"State two ways to manufacture ethanol"**: fermentation of glucose; catalytic addition of steam to ethene.
- **Word equation to complete**: glucose → ethanol + carbon dioxide; ethene + steam → ethanol. Nothing else is formed: no water, no oxygen.
- **Multiple choice on conditions**: $300\ ^\circ\mathrm{C}$ and $60\ \mathrm{atm}$ go with ethene; 25–$35\ ^\circ\mathrm{C}$ goes with fermentation. Reject $55\ ^\circ\mathrm{C}$ or $300\ ^\circ\mathrm{C}$ for fermentation, and $30\ ^\circ\mathrm{C}$ for ethene. **Check the unit:** $60\ \mathrm{atm} = 6000\ \mathrm{kPa}$**.** A row with "300" and "6000" is right when the pressure is in kPa, and wrong when it is in atm. Ethanol is not made directly from ethane.
- **Raw materials of the two processes**: glucose, ethene and steam (not ethane).
- **Type of reaction for ethene + steam**: addition; "state why it is addition": **only one product is formed**. Statements that are true: the product (M_r 46) is heavier than ethane (M_r 30); fewer electrons are shared between the carbons afterwards. False: it forms two products, it is redox, it happens in cold water, the product decolourises aqueous bromine.
- **Extended: which alkene?** $\mathrm{C}_x\mathrm{H}_y + \mathrm{H_2O} \rightarrow \mathrm{C}_x\mathrm{H_5OH}$ has $x = 2$, $y = 4$ (ethene). An alcohol $\mathrm{C_3H_7OH}$ comes from propene; propene gives **two** alcohols, ethene only one.
- **Extended: a two-step route** such as a long alkane → ethene (cracking, e.g. $\mathrm{C_{12}H_{26}} \rightarrow \mathrm{C_2H_4} + \mathrm{C_{10}H_{22}}$) → ethanol (addition): name each reaction type and write each equation.

2. Recognise, name and draw alcohols and carboxylic acids (57 questions)

1. **Draw ethanol or ethanoic acid** with every atom and bond (Core's most common part). Check each C has four bonds, each O two, each H one, and the acid has **C=O** drawn as a double line. Don't leave out the O–H bond: an –OH written as a group without its bond loses a mark.
2. **Circle a functional group** on an unfamiliar molecule. Alcohol: ring the **O–H** attached to a carbon (not a –COOH's OH). Carboxylic acid: ring the **whole –COOH** (the C, the =O and the –O–H).

3. **Name the series**: alcohols, carboxylic acids. **General formulae**: $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{OH}$, $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{COOH}$.

Variations you will meet:

- **Molecular formula from a displayed or structural formula**: count every atom, including the H in each –OH and –COOH. Butane-1,4-diol, $\mathrm{HOCH_2CH_2CH_2CH_2OH}$, is $\mathrm{C_4H_{10}O_2}$.
- **Formula of a member with n carbons**: alcohol $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{OH}$ (7 carbons: $\mathrm{C_7H_{15}OH}$); acid with 3 carbons: $n = 2$ in $\mathrm{C}_n\mathrm{H}_{2n+1}\mathrm{COOH}$, so $\mathrm{C_2H_5COOH}$ ($\mathrm{C_3H_6O_2}$).
- **A table of a homologous series**: state the trend (boiling point increases as the number of carbon atoms increases), deduce a missing formula from the pattern, predict a missing value **between** its two neighbours (not outside them).
- **"Define homologous series"** (2 marks): a family of similar compounds with similar chemical properties (1) because they have the same functional group (1). Other characteristics that earn marks: same general formula; each differs from the next by $\mathrm{CH_2}$; a trend in physical properties.
- **Why ethanol is not a hydrocarbon**: it contains oxygen (not only carbon and hydrogen).
- **Multiple choice**: pick the structure of ethanol ($\mathrm{CH_3CH_2OH}$, not $\mathrm{CH_3CH_3}$, $\mathrm{CH_2CH_2}$ or $\mathrm{CH_3COOH}$) or of an acid (count the carbons, including the C of COOH). Count bonds: ethanol has 8 single bonds; ethanoic acid has 3 C–H, 1 C–C and 1 C=O. Which structure is an alcohol: the one with C–O–H.
- **Extended: draw and name an isomer**: $\mathrm{C_3H_8O}$ alcohols are propan-1-ol and propan-2-ol (the –OH on the end or the middle carbon); a carboxylic acid with the same formula as an ester (see type 4).
- **Extended: empirical formula**: divide by the highest common factor. Methanoic acid $\mathrm{CH_2O_2}$ stays as it is; butanedioic acid $\mathrm{C_4H_6O_4}$ becomes $\mathrm{C_2H_3O_2}$.
- **Extended: an acid made from a molecule** (for example by oxidising something with two carbons): draw ethanoic acid and name it.

3. Reactions of carboxylic acids as acids (49 questions)

1. **Identify what is added**: a metal, a base (oxide or hydroxide) or a carbonate.
2. **Write the products**: metal → salt + **hydrogen**; base → salt + **water**; carbonate → salt + **carbon dioxide** + **water**.
3. **Name the salt**: metal name + **ethanoate** (sodium ethanoate, potassium ethanoate, calcium ethanoate, magnesium ethanoate). Spell it "ethanoate".
4. **Formula of the salt**: $\mathrm{CH_3COO^-}$ with the metal ion's charge balanced: $\mathrm{CH_3COOK}$, $\mathrm{(CH_3COO)_2Mg}$. The acid's H is gone: $\mathrm{Ca(CH_3COOH)_2}$ is wrong.

Variations you will meet:

- **Observations** (Core, 2 marks): with magnesium, zinc, sodium or a carbonate: **bubbles / fizzing**, and the solid **gets smaller or disappears**. With indicators: blue litmus → **red**; universal indicator → **yellow or orange** (red is accepted too); methyl orange → red.
- **Choose the pH** of dilute ethanoic acid from a list: about 3 to 6 (for example pH 5), below 7 but not pH 1.

- **Multiple-choice statements.** True: it contains –COOH; it has a pH below 7; it reacts with metal carbonates to give carbon dioxide; it reacts with reactive metals to give a salt and hydrogen; it reacts with alkalis to give a salt and water; it reacts with an alcohol to give an ester. False: pH 10 or above 7; turns red litmus blue; turns methyl orange yellow; carbonates give hydrogen; metal oxides give oxygen; hydroxides give hydrogen; reacts with copper; reacts with ammonium salts to give ammonia; it is a strong acid.
- **Ethanoic acid and hydrochloric acid** both contain hydrogen and both react with carbonates; only ethanoic acid contains carbon.
- **Identify a compound from test results**: reacts with a carbonate (or copper(II) carbonate) to give a gas, pH 3, soluble, turns litmus red → a **carboxylic acid** (ethanoic acid if it has two carbons). No reaction with aqueous bromine and burns → not an alkene; the "burns" result alone does not rule out an acid.
- **A solid dissolves in excess ethanoic acid with no bubbles** and gives a colourless solution: a hydroxide or an oxide of a metal with colourless ions (calcium hydroxide), not a metal or carbonate (bubbles) and not copper(II) oxide (blue solution).
- **Extended: symbol equations**: $2C_3H_7COOH + Na_2CO_3 \rightarrow 2C_3H_7COONa + CO_2 + H_2O$: one mark for the salt's formula, one for the rest. Other acids: propanoic acid with sodium carbonate gives **sodium propanoate**; its anion is $CH_3CH_2COO^-$.
- **Extended: a pH change as acid forms** (for example an ester reacting with water): pH starts at 7 and falls to between 3 and 7; the ion responsible is H^+; follow it with universal indicator.
- **Reading a pH curve** (Core): the starting pH is where the curve meets the vertical axis; the neutral volume is where it crosses pH 7. Read carefully from the grid, to the nearest small square. If the acid is added to the alkali instead, the curve starts high (about pH 13) and falls.
- **Which compound reacts with aqueous sodium hydroxide?** The carboxylic acid, because acids react with alkalis (bases).

4. Esters: name, make, draw (41 questions)

Extended only.

1. **Name from the parents**: alcohol → **-yl**, acid → **-oate**, alcohol part first: butanoic acid + methanol → **methyl butanoate**.
2. **Parents from the name**: "ethyl" → ethanol, "propyl" → propan-1-ol, "butyl" → butan-1-ol; "-oate" → the acid (propanoate → propanoic acid).
3. **Name from a structural or displayed formula**: find COO (or the C=O). The side with the C=O carbon is the acid (count its carbons, including that one); the side beyond –O– is the alcohol.
4. **Conditions and the other product**: an **acid** catalyst (concentrated sulfuric acid; "acid" is the type), warm; the other product is **water**.

Variations you will meet:

- **Draw an ester's displayed formula**: one mark for a correct linkage (C=O and –O– with all bonds), one for the whole molecule right. Draw the acid part, then C(=O)–O–, then the alcohol chain. The ester "with two carbon atoms" is methyl methanoate, $HCOOCH_3$; with three carbons, methyl ethanoate or ethyl methanoate.

- **Circle the ester linkage**: ring the C=O carbon, both oxygens and the carbon joined to the single-bonded O (two C and two O).
- **Multiple choice with swapped halves**: $\mathrm{CH_3COOCH_3}$ is methyl **ethanoate**, not ethyl methanoate; $\mathrm{HCOOCH_2CH_2CH_3}$ is propyl methanoate (from methanoic acid and propan-1-ol). Check both halves before choosing.
- **Molecular and empirical formula**: add the carbons: ethyl butanoate is $\mathrm{C_6H_{12}O_2}$, empirical $\mathrm{C_3H_6O}$. In $\mathrm{C_nH_{2n}O_2}$, n is the total number of carbons (butyl propanoate: $4 + 3 = 7$).
- **Structural isomers**: another unbranched ester with the same formula (move carbons from one side to the other: propyl methanoate ↔ methyl propanoate ↔ ethyl ethanoate), or the acid with the same number of carbons (methyl methanoate ↔ ethanoic acid). **"How many unbranched esters?"**: $n - 1$.
- **Diols**: 1 mol of a diol reacts with **2** mol of ethanoic acid; the product has two ester linkages, and 2 mol of water form.
- **The reverse reaction** (an ester + water): name the acid and alcohol it gives, exactly as above.
- **Combustion of an ester**: $\mathrm{C_nH_{2n}O_2}$ gives $n\mathrm{CO_2} + n\mathrm{H_2O}$; O atoms needed $3n$, minus the 2 in the ester, halved.
- **"Which type of substance forms when an acid and an alcohol are warmed with an acid catalyst?"**: an ester (not a salt, an alkene or a polymer). A letter question "the formation of an ester" is the equation with acid + alcohol → ester + water.

5. Uses of ethanol and its combustion (23 questions)

1. **Uses**: **fuel** and **solvent**. If one is given, write the other.
2. **Why it is a fuel**: it **releases energy (heat) when it burns** (combustion is exothermic). Being colourless, low-density or forming $\mathrm{CO_2}$ is not the reason.
3. **Complete combustion products**: **carbon dioxide and water** (word equation: ethanol + oxygen → carbon dioxide + water).
4. **Incomplete combustion**: **carbon monoxide** (the toxic gas) and **carbon**, plus water.

Variations you will meet:

- **Extended: the balanced equation** $\mathrm{C_2H_5OH + 3O_2 \rightarrow 2CO_2 + 3H_2O}$ (one mark for $\mathrm{CO_2}$ and $\mathrm{H_2O}$ as the only products, one for balancing). For an ester such as $\mathrm{C_5H_{10}O_2}$: $\mathrm{2C_5H_{10}O_2 + 13O_2 \rightarrow 10CO_2 + 10H_2O}$.
- **Multiple choice**: "water is produced when alcohols burn" is true; "ethanol contains a C=C" is false; a compound $\mathrm{C_2H_6O}$ is used as a fuel (it is ethanol: not unsaturated, not an acid, not made from ethane).
- **Which process in a scheme is combustion**: the step that makes carbon dioxide and water from ethanol and oxygen, not fermentation (which also makes $\mathrm{CO_2}$, but from glucose and yeast, with no oxygen).
- **Pick from a list**: "used as a fuel" → ethanol.

6. Compare fermentation with steam + ethene (17 questions)

Extended only.

1. **Fermentation advantages**: **renewable** raw material (crops); **low temperature**, so **less energy**; normal pressure. **Disadvantages**: **slow**; **batch** process; **dilute, impure** ethanol that must be distilled.
2. **Steam + ethene advantages**: **fast**; **continuous**; almost **pure** ethanol. **Disadvantages**: **non-renewable** raw material (petroleum); **high temperature and pressure**, so a lot of energy.
3. Read which method and whether the question wants an **advantage** or a **disadvantage**, then check **every** entry in the chosen row.

Variations you will meet:

- **Distractors put a disadvantage in the advantage column**: "batch process", "slow", "needs distilling", "non-renewable", "uses more energy" are never advantages.
- **Statements about both methods**: both use a catalyst (yeast is one); they do **not** use similar amounts of energy; fermentation does not need $60\ \text{atm}$; steam + ethene does not run at 25–$35\ ^\circ\text{C}$. "No greenhouse gases" and "ethanol is the only product of fermentation" are false.
- **Paper 4, "give one advantage of each method"**: fermentation, renewable raw material; steam + ethene, fast (or continuous, or pure ethanol). Other creditworthy fermentation advantages: conserves fossil fuels; lower temperature (less energy); lower pressure.

7. Oxidation of ethanol to ethanoic acid (16 questions)

Extended only.

1. **Name the reagent**: **acidified aqueous potassium manganate(VII)** (heat), or **bacteria** (bacterial oxidation, making vinegar).
2. **Name the reaction**: **oxidation**. The product is a **carboxylic acid**. Ethanol is the **reducing agent**.
3. **Predict the product from another alcohol**: keep the carbons, turn –CH_2OH into –COOH: propan-1-ol → CH_3CH_2COOH (propanoic acid); a diol → a di-acid.

Variations you will meet:

- **Multiple choice on reaction type**: oxidation, not reduction, dehydration, fermentation, neutralisation, condensation, hydrolysis, addition or combustion. "Ethanol is reduced by bacteria" is false.
- **"Which processes make ethanoic acid?"**: heating ethanol with acidified potassium manganate(VII), and bacterial oxidation. Not distilling ethanol.
- **Bacterial oxidation of ethanol gives** vinegar (not ethene, sodium ethanoate or an ester).
- **A two-step route**: ethanol → ethanoic acid (oxidation), then ethanoic acid + ethanol → ethyl ethanoate (ester formation).
- **Identify from a formula**: a compound with 2 carbons and 4 hydrogens made by oxidising an alcohol is ethanoic acid, $C_2H_4O_2$.
- **A reaction scheme**: "ethanol heated with dilute sulfuric acid and another reagent" → potassium manganate(VII); the product is in the carboxylic acid series; draw ethanoic acid.

Worked examples

The bold codes show where marks are earned, as in Cambridge mark schemes. The number is how many marks.

- **M1** method mark: for a correct method, even if the numbers slip.
- **A1** accuracy mark: for a correct answer; it needs the M mark before it.
- **B1** mark for a correct result on its own, with no method needed.

Example 1

Dilute aqueous ethanoic acid is tested in three ways.

(a) A few drops of universal indicator are added. Suggest the colour seen and the pH. **[2]**

(b) Granules of zinc are added. Give one observation, and name the two products. **[3]**

(c) Complete the word equation: ethanoic acid + potassium carbonate → ... **[2]**

(d) Give the formula of the salt formed in (c). **[1]**

(e) Explain why no gas is given off when ethanoic acid is added to aqueous potassium hydroxide. **[1]**

(a) Orange (or yellow) **B1**; pH 4 (any value from 3 to 6) **B1**. It is a weak acid, so not pH 1.

(b) Bubbles (fizzing), and the zinc gets smaller **B1**; zinc ethanoate **B1** and hydrogen **B1**.

(c) ethanoic acid + potassium carbonate → potassium ethanoate + carbon dioxide + water. **B1** for potassium ethanoate, **B1** for carbon dioxide and water.

(d) $\mathrm{CH_3COOK}$. **B1** (The ethanoate ion is $\mathrm{CH_3COO^-}$ and $\mathrm{K^+}$ has a charge of $1+$.)

(e) Potassium hydroxide is a base (an alkali), and an acid with a base gives only a salt and water. **B1**

Example 2

A company makes ethanol for fuel from sugar cane. Sugar from the cane gives aqueous glucose, which is fermented.

(a) State three conditions needed for fermentation. **[3]**

(b) (Extended) Write the symbol equation for fermentation. **[2]**

(c) (Extended) Calculate the maximum mass of ethanol that can be made from 450 g of glucose. (M_r: glucose $= 180$, ethanol $= 46$) **[2]**

(d) The ethanol is burned as a fuel. Write the balanced equation for its complete combustion, and name the toxic gas formed if the oxygen supply is limited. **[3]**

(e) (Extended) Another company makes ethanol from ethene. Give one advantage of the sugar-cane method, and one advantage of the ethene method. **[2]**

(a) Yeast **B1**; a temperature of 25–$35\ ^\circ\mathrm{C}$ (for example $30\ ^\circ\mathrm{C}$) **B1**; absence of oxygen **B1**. (Aqueous glucose is the reactant, not a condition, so it earns no mark here.)

(b) $\mathrm{C_6H_{12}O_6} \rightarrow 2\mathrm{C_2H_5OH} + 2\mathrm{CO_2}$. **M1** for glucose as the only reactant, **A1** for the balanced equation.

(c) Moles of glucose $= 450 \div 180 = 2.5$ mol, so moles of ethanol $= 2 \times 2.5 = 5$ mol **M1**. Mass $= 5 \times 46 = 230$ g **A1**.

(d) $\mathrm{C_2H_5OH} + 3\mathrm{O_2} \rightarrow 2\mathrm{CO_2} + 3\mathrm{H_2O}$. **M1** for $\mathrm{CO_2}$ and $\mathrm{H_2O}$ as the only products, **A1** for the balancing (O: $4 + 3 = 7$ needed, less 1 in ethanol, $= 6$ atoms $= 3\mathrm{O_2}$). Carbon monoxide **B1**.

(e) Sugar cane: a renewable raw material (or less energy needed) **B1**. Ethene: faster (or continuous, or it gives purer ethanol) **B1**.

Example 3 (Extended)

Butan-1-ol has the structural formula $\mathrm{CH_3CH_2CH_2CH_2OH}$.

(a) Give the molecular formula of butan-1-ol, and show that it fits the general formula of the alcohols. **[1]**

(b) Butan-1-ol is heated with acidified aqueous potassium manganate(VII). Name the type of reaction, and name and give the structural formula of the organic product. **[3]**

(c) The product of (b) reacts with magnesium. Give the formula of the salt and name the gas. **[2]**

(d) Butan-1-ol is warmed with methanoic acid and a few drops of concentrated sulfuric acid.

(i) State the role of the sulfuric acid. **[1]**

(ii) Name the ester formed and give its structural formula. **[2]**

(iii) Name the other product. **[1]**

(iv) Give the molecular formula of the ester, and name one other unbranched ester that is a structural isomer of it. **[2]**

(a) $\mathrm{C_4H_9OH}$ ($\mathrm{C_4H_{10}O}$): with $n = 4$, $2n + 1 = 9$. **B1**

(b) Oxidation **B1**. Butanoic acid **B1**, $\mathrm{CH_3CH_2CH_2COOH}$ **B1** (the –$\mathrm{CH_2OH}$ end becomes –COOH; still four carbons).

(c) $\mathrm{(CH_3CH_2CH_2COO)_2Mg}$ **B1**: two butanoate ions for one $\mathrm{Mg^{2+}}$. Hydrogen **B1**.

(d)(i) A catalyst. **B1**

(ii) Butyl methanoate **B1**: "butyl" from butan-1-ol, "methanoate" from methanoic acid. $\mathrm{HCOOCH_2CH_2CH_2CH_3}$ **B1**: the acid part (HCOO) is written first.

(iii) Water. **B1**

(iv) $\mathrm{C_5H_{10}O_2}$ ($1 + 4 = 5$ carbons, $\mathrm{C_nH_{2n}O_2}$) **B1**. Move carbons from the alcohol side to the acid side: propyl ethanoate, ethyl propanoate or methyl butanoate (any one) **B1**.

Example 4 (multiple choice)

(a) Propanoic acid reacts with aqueous potassium hydroxide. Which row is correct? **[1]**

	name of salt	formula of salt	other product
A	potassium propanoate	$\mathrm{CH_3CH_2COOK}$	water
B	potassium propanoate	$\mathrm{CH_3CH_2COOK}$	hydrogen
C	potassium propanol	$\mathrm{CH_3CH_2OK}$	water
D	potassium propanoate	$\mathrm{CH_3CH_2COOK}$	carbon dioxide and water

(b) (Extended) Which row gives a disadvantage of each method of making ethanol? **[1]**

	fermentation	steam + ethene
A	renewable raw material	continuous process
B	slow reaction	non-renewable raw material
C	batch process	fast reaction
D	low temperature	high energy use

(c) A colourless liquid, X, dissolves in water to give a neutral solution. It burns in air, does not react with magnesium or with sodium carbonate, and does not decolourise aqueous bromine. What is X? **[1]**

A ethanoic acid B ethanol C ethene D hexane

(d) (Extended) 0.30 mol of ethanoic acid reacts completely with excess sodium carbonate: $\mathrm{2CH_3COOH + Na_2CO_3 \rightarrow 2CH_3COONa + CO_2 + H_2O}$. How many moles of carbon dioxide form? **[1]**

A 0.15 B 0.30 C 0.45 D 0.60

(a) A hydroxide is a base, so the products are a salt and water only: hydrogen comes from metals (B) and carbon dioxide from carbonates (D). The salt of propanoic acid is a propanoate, $\mathrm{CH_3CH_2COO^-}$ with $\mathrm{K^+}$; C is named after an alcohol. **Answer A.**

(b) A, C and D each put an advantage somewhere. Fermentation is slow; ethene comes from petroleum, which is non-renewable. **Answer B.**

(c) It is not an acid (neutral, no reaction with Mg or a carbonate), not an alkene (bromine unchanged), and it dissolves in water (hexane does not). **Answer B.**

(d) 2 mol of acid give 1 mol of $\mathrm{CO_2}$, so $0.30 \div 2 = 0.15$ mol. **Answer A.**

Common mistakes

- **Mixing up the two methods.** Fermentation: glucose, yeast, 25–$35\ ^\circ\mathrm{C}$, no oxygen. Ethene: steam, acid catalyst, $300\ ^\circ\mathrm{C}$, $60\ \mathrm{atm}$. Examiners see fermentation conditions given for the ethene process, and the other way round, every year.
- **"Water" instead of "steam"**, and **"temperature" or "pressure" with no value.** Give the reagent as steam and the numbers with units.
- **Wrong fermentation products.** Glucose gives ethanol and **carbon dioxide**; not water, not oxygen.
- **Keeping the acid's H in the salt.** Calcium ethanoate is $(\mathrm{CH_3COO})_2\mathrm{Ca}$, not $\mathrm{Ca(CH_3COOH)_2}$; magnesium ethanoate is not $\mathrm{CH_3COOMg}$.
- **Misspelling or misnaming the salt.** Write "ethanoate", not "ethanate", "ethanoic" or "ethanol".
- **Giving hydrogen from carbonates** or oxygen from metal oxides. Metal → hydrogen; carbonate → carbon dioxide; base → water only.
- **Saying ethanoic acid turns red litmus blue.** Acids turn blue litmus red.
- **Swapping the halves of an ester name.** The alcohol part (-yl) comes first in the name; in the formula it is usually written last. Ethyl propanoate and propyl ethanoate are different. Names ending in "acid" or "-anol" are not ester names.
- **Drawing an ester without its full linkage.** Show the C=O and the –O– with every bond.
- **Naming the wrong oxidising agent.** It is acidified potassium manganate(VII), not "potassium manganate" alone or another reagent. The change is oxidation, not reduction.
- **Uses of ethanol that the question has already given, or "making bread".** Answer fuel or solvent.
- **Not drawing the O–H bond** in ethanol or ethanoic acid. Every bond counts.
- **Putting a disadvantage in the advantage column** in the comparison: "batch process" and "needs distilling" are disadvantages of fermentation.

How to get the marks

- **"State" and "Name"** want the exact word: fermentation, addition, steam, yeast, oxidation, ester, water, carbon dioxide, hydrogen, sodium ethanoate, acid (catalyst).
- **"State two conditions"**: give two different ones, each on its own line: a temperature with its unit, the catalyst (yeast, or acid), the pressure, "absence of oxygen". An extra wrong condition can cancel a right one, so don't list everything you know.
- **"Describe the observations"**: what you would **see**: bubbles, fizzing, the solid disappearing, a colour change "from ... to ...". "Hydrogen is formed" is a product, not an observation.
- **"Complete the word equation"**: all the products, spelled correctly.
- **Symbol equations**: formulae first, then balance. One mark is usually for the right substances and one for the balancing, so write the formulae even if you can't balance.

- **"Draw the displayed formula"**: every atom and every bond, C=O as two lines, O–H drawn.
- **"Name the ester"**: alcohol part (-yl) + acid part (-oate), as one name. **"Name the acid and alcohol"**: give full names (propan-1-ol, butan-1-ol) on the right lines.
- **"Give one advantage of each method"**: label which is which, and give an advantage, not a fact such as "uses yeast".
- **"Deduce" or "Predict"** from a table: use the pattern and stay between neighbouring values.
- **"Suggest"**: apply what you know to a new compound: a new acid's salt is "...anoate", a new alcohol oxidises to the acid with the same carbons.

Quick check

1. Name the products when dilute ethanoic acid reacts with (a) lithium and (b) calcium oxide.
2. Write the balanced symbol equation for the complete combustion of propan-1-ol, $\mathrm{C_3H_7OH}$.
3. Magnesium ribbon is added to dilute ethanoic acid, and a second piece to ethanol. Describe what is seen in each.
4. (Extended) Name the three unbranched esters with the molecular formula $\mathrm{C_4H_8O_2}$, and name the carboxylic acid with the same formula.
5. (Extended) An alcohol X is oxidised to a carboxylic acid with $M_\mathrm{r} = 74$. Identify the acid and X. (A_r: C = 12, H = 1, O = 16)

Answers

1. (a) Lithium ethanoate and hydrogen. (b) Calcium ethanoate and water (a base gives no gas).
2. C: $3\mathrm{CO_2}$; H: $8 \div 2 = 4\mathrm{H_2O}$; O needed $6 + 4 = 10$, less 1 in the alcohol, $= 9$ atoms, $4\frac{1}{2}\mathrm{O_2}$. Doubled: $2\mathrm{C_3H_7OH} + 9\mathrm{O_2} \rightarrow 6\mathrm{CO_2} + 8\mathrm{H_2O}$.
3. With ethanoic acid: bubbles (fizzing) and the magnesium gets smaller and disappears, as hydrogen and magnesium ethanoate form. With ethanol: no change, because ethanol is not an acid.
4. With 4 carbons there are $4 - 1 = 3$: methyl propanoate ($\mathrm{CH_3CH_2COOCH_3}$), ethyl ethanoate ($\mathrm{CH_3COOCH_2CH_3}$) and propyl methanoate ($\mathrm{HCOOCH_2CH_2CH_3}$). The acid is butanoic acid, $\mathrm{CH_3CH_2CH_2COOH}$.
5. For $\mathrm{C_nH_{2n+1}COOH}$, $M_\mathrm{r} = 12n + (2n + 1) + 12 + 32 + 1 = 14n + 46$. $14n + 46 = 74$ gives $n = 2$: $\mathrm{C_2H_5COOH}$, propanoic acid. Oxidation keeps the three carbons, so X is propan-1-ol, $\mathrm{CH_3CH_2CH_2OH}$.

Past questions to try

- **0620/41/O/N/23 Q6**: both ways of making ethanol, an advantage of each, oxidation to ethanoic acid, and the calcium salt.
- **0620/42/O/N/22 Q6**: methanoic acid, an ester with propan-1-ol, and its isomers.
- **0620/31/M/J/21 Q4**: observations with magnesium and litmus, and reading a pH curve.
- **0620/42/O/N/21 Q6**: the combustion equation of ethanol, a diol making two ester linkages, and oxidising a diol.